Hexagonal Microstrip Patch Antenna Design for UWB Application

Khushboo Singh [1*], *Sonal Patil* [1*], *Ashwini Naik* [1*], *and Sujata Kadam* [1*]

[1]Electronics and Telecommunication Engineering Department, Ramrao Adik Institute of Technology, Nerul, Navi Mumbai.

Abstract. Microstrip patch antennas is one of the most used antennas for wireless communication. Its key features include a limited bandwidth, low cost, and ease of manufacture. This paper describes about the design of microstrip patch antenna over the frequency range of 3.1 GHz to 10.6 GHz for UWB applications. The substrate material chosen is FR4, having a loss tangent of 0.02, dielectric constant of 4.4, and substrate thickness of 1.59 mm. This work presents design of microstrip antenna with hexagonal shaped radiating patch. An antenna is modelled and analysed using HFSS 2021 R2 software. The antenna structure provides return loss which is less than -10 dB and a VSWR less than 2 over the specified frequency range. The simulated results of proposed hexagonal shaped microstrip patch antenna provides a peak gain of 5.32 dB with radiation efficiency of 90.88 %. The planned antennas can be used for UWB applications.

Keywords. MSA, UWB, Gain and Radiation pattern.

1 Introduction

Wireless communication is one of the most rapidly evolving and dynamic technology areas within the field of communication. Wireless communications are now the frequently used in both human daily activities and industrial purposes. The most common wireless communication is a microstrip patch antenna. The key attributes of microstrip patch antennas are a cost feasibility, ease of fabrication and limited bandwidth.

A rectangular microstrip patch antenna of a I-shaped and dual C-slotted have been designed for 10 GHz. The breast cancer tumour is detected by the planned antenna which has bandwidth of 7.51dB, covers the frequency band of 4.9 to 7.89 GHz, has a return loss of less than -37dB, and has an antenna gain of a 2.45dB. The rectangular patch antenna is flexible and an efficiency of 87.1% were obtained [1]. The breast cancer detection system is used in compact UWB antenna have been designed. Here, the antenna has a frequency band of 3 to 12 GHz and an UWB of 120% for FCC band, with an overall size of 35mm x 20mm x 1.6mm. The suggested antenna features high gain, radiation patterns that are omnidirectional and good impedance matching [2]. The rectangular microstrip patch antenna for an UWB have been designed for microwave breast cancer detection and have evaluated the data mining in the classification and accuracy using random forest algorithm. Here, the rectangular MSA is designed over wide frequency range around 3 to 18 GHz. The random forest algorithm has been determined using breast cancer with a 94% accuracy, according to the classification results [3]. For UWB applications, a simple and compact microstrip-fed slot antenna have been proposed, which comprises of a circular patch as well as an open T-slot to implement a microstrip-line into slot transition over a broader frequency range. The observations and simulations show that such a simple structure, with its proposed system, from 2.5 to 12.5 GHz (bandwidth = 133.3%), yields a broadband impedance bandwidth with 10 dB return loss that can be adjusted by changing its parameters [4]. A new proximity-fed printed slot antenna with dual band notches for 3.5/5.5 GHz features have been designed and analysed. The designed circular microstrip patch antenna meets a return loss of -10 dB criterion over a frequency range of 2.7 to 17 GHz. To achieve dual band notched characteristics at 3.5 and 5.5 GHz, with an open ring slot has been etched off the circular patch as well as a -shaped slot has been etched off the microstrip feeding line [5]. A hexagonal monopole antenna which is relatively compact for UWB applications have been designed using 2 antennas which are fed to the single microstrip line over a frequency band of 4 to 14 GHz. The impedance bandwidth of the proposed antenna1 is approximately 111 %. The designed antenna2 has an impedance bandwidth for lower frequency is 31.58% and for higher frequency is 62.54%. A frequency notched band of 6.05 to 7.33 GHz was projected, while 6.22 to 8.99 GHz was observed, resulting in a single narrow band with axial ratio (1.435) have been achieved [6]. A slotted ground of three hexagonal MSA have been achieved using a circular polarization. The three hexagonal patch antennas are as simple patch, slotted ground patch, and parasitic element patch. The simple patch has a 2% impedance bandwidth, the patch with slotted ground has a 5.2% impedance bandwidth, and also the antenna including parasitic

* Corresponding author: khushis7891@gmail.com sonalpatil606a@gmail.com ashwini.naik@rait.ac.in sujata.kadam@rait.ac.in

element has a 6.35% impedance bandwidth. The patch with slotted ground has a measured axial ratio of 4.73%, while the patch with parasitic element has a measured axial ratio of 3.33%. Within the operating band, the suggested FSS provides a gain enhancement of roughly 3 dB [7]. A Novel modified Hexagonal microstrip antenna with curved partial ground plane have been proposed using UWB. Here, a modified hexagonal microstrip patch antenna has a 3.6 dB average gain (maximum gain ranging from 1.9 to 5.4 dB) and a relatively flat group delay and an impedance bandwidth of 3 to 11.3 GHz. The detected radiation pattern is observed as an omnidirectional [8]. The microstrip-fed hexagonal type UWB monopole with triple notched bands is used in the antenna. Two inverted T-shaped conductor backed planes, a microstrip feed line, and a regular hexagonal radiation patch with such a complementary split ring resonator (CSRR) placed inside an antenna underside make up the antenna. Here, the simulation and measurement result revealed that such a monopole UWB antenna can operate at frequencies ranging from 2.93 to 10.04 GHz with a return loss of -10 dB bandwidth, with the exception of 3 notched bands at 3.31 to 3.78 GHz, 5.33 to 5.77 GHz, and 7.24 to 7.72 GHz for dismissing WiMAX as well as downlink X-band satellite communications network signals [9]. A hexagonal microstrip patch antenna has been designed and simulated using breast cancer detection. Here, the antenna is mimicked by embedding a hexagon slot in the patch's centre, resulting in an impedance bandwidth of approximately 5 GHz [10]. A hexagonal and octagonal microstrip patch antenna has been implemented for UWB applications. For the designed antenna, the strip is built with a gap of d=3mm and length of 23mm between strip and ground planes to achieve matching. A geometry of hexagonal monopole is 10mm wide whereas octagonal has 9mm wide. The 2 printed monopole antennas have a total dimension of 45 x 60 x 1.6 mm and are etched on a FR-4 epoxy substrate. A Hexagonal strip monopole has a 5.5 GHz resonant frequency and a UWB impedance bandwidth around ($S11 < -10$ dB) of 1.54 - 9.41 GHz, whereas a octagonal strip monopole has a 5.5 GHz resonant frequency as well as a UWB impedance bandwidth around ($S11 < -10$ dB) of 1.3 - 5.65 GHz. Hexagonal has a VSWR of 1.52:1 over 2.09 GHz and Octagonal has a VSWR of 1.53:1 over 1.78GHz. Hexagonal has a bandwidth of 7.87GHz, whereas Octagonal has a bandwidth of 4.35GHz [11]. A hexagon shaped microstrip patch antenna has been designed and fabricated in three bands. The antenna is made up of a partial ground plane and hexagonal patch, which has the overall dimensions of 15 x 17 x 1.6 mm, therefore it works at three frequencies: 5.40, 6.76 and 8.82 GHz for TV satellite broadcasting, WLAN, WiMAX (5250 - 5850 MHz), 5.2 to 5.7 GHz for 5G Unlicensed band, 5.47 to 5.725 GHz for IEEE 802.11a, radar and weather monitoring [12].

2 Antenna Design Theory

2.1. Microstrip Patch Antenna (MSA)

Microstrip antennas are becoming increasingly important in the era of today's wireless communication. Antennas of various sorts have been developed for different wireless applications. The MSA is among the most suitable and attractive type of antenna compared to other antennas due to its light weight and smaller size. Microstrip patch antenna provides a numerous advantage, including conformability to mounting hosts, low profile, and ease of fabrication. Size reduction as well as bandwidth increase are also key design concerns for microstrip antennas within practical applications. These lightweight microstrip antennas are affordable, and durable. Their fabrication process is simple as it involves etching and photolithography, also simple feeding mechanism. The microstrip circuit elements are simple to utilise in an array or to combine with other microstrip circuit elements. Microstrip antennas are simple to integrate with MMICs and MICs. They are durable when installed on a device's hard surface. The antenna architecture and the feedline and matching network can be done at the same time. Microstrip patch antennas were born out of the desire to use printed circuit technology not just for transmission lines and circuit components, as well as for the radiating portions of an electronic system.

A metal patch and a ground plane are separated by a thin dielectric substance in a microstrip patch antenna. These antennas can be fed by using proximity feed, aperture coupled feed, microstrip line feed, and coaxial probe feed techniques. The energy is initially steered or linked to the region beneath the patch, which works as a resonant cavity with the open circuits on both of sides. Some of energy escapes the cavity and it is radiated into space, forming an antenna.

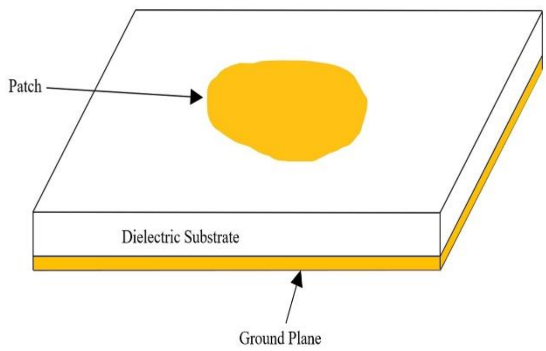

Fig. 1. Microstrip Patch Antenna

The figure 1 shows the basic structure of microstrip patch antenna. MSA can be made up of various shapes such as square, rectangular, circular, dipole, elliptical, circular ring, hexagonal and so on. Patch antennas are by far the most prevalent type of a micro strip antenna.

2.2 Design Theory of Microstrip Patch Antenna

Here, MSA is configured using hexagonal shaped radiating patch. The structure is designed to operate in the ultra-wideband frequency range of 3.1 to 10.6 GHz. The radius of Hexagonal Patch (a_h) is given by,

$$a_h = \frac{F}{\sqrt{\left\{1+\frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}}} \quad (1)$$

Where,

$$F = \frac{8.791 \times 10^9}{f_\circ \sqrt{\varepsilon_r}}$$

The side length of hexagonal patch (l) is given by,

$$\pi a_h^2 = l^2 \frac{3\sqrt{3}}{2} \quad (2)$$

The height of hexagonal patch (L) is given by,

$$L = \sqrt{3}\, a_h \quad (3)$$

2.3 Proposed Structure

The MSA for ultra-wideband applications is proposed. The antenna structure consists of a dielectric substrate on one side which is a hexagonal shaped metallic radiating patch, and on the other side is a metallic ground plane. The substrate material chosen is of FR4. The relative permittivity, thickness and a loss tangent of FR4 substrate is 4.4, 1.59 mm and 0.02 respectively. Microstrip line model is used to feed the antenna. The antenna structure is modelled using HFSS 2021 R2 software. Ansys HFSS is a three-dimensional electromagnetic (EM) simulation software for developing and simulating high frequency electrical products like antennas. The antenna parameters are designed at resonating frequency of 6.85 GHz to cover frequency band range of 3.1 GHz - 10.6 GHz. The designed dimensions of hexagonal patch were obtained as radius of 10 mm, side length of 11 mm and height of 17.3 mm. The antenna structure is optimized to obtain return loss less then - 10 dB and VSWR less than 2. The geometry of proposed antenna structure and details of design dimensions are shown in figure 2 and 3 respectively. The optimized values of control parameters of HMSA are listed in the table 1.

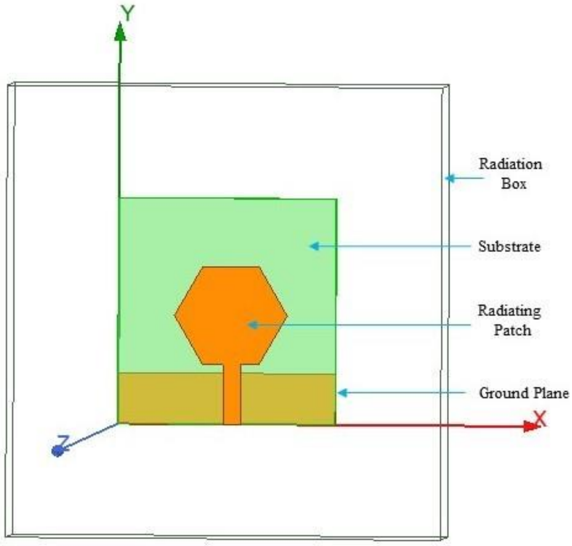

Fig. 2. Geometry of proposed antenna structure

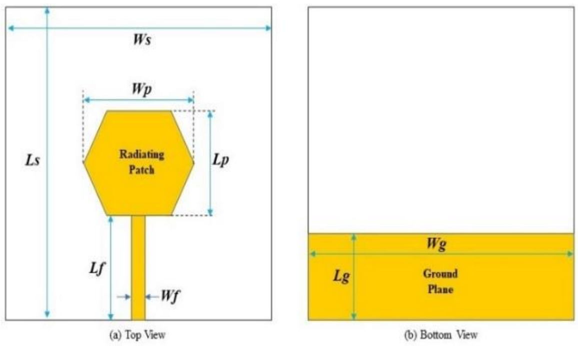

Fig. 3. Design details of dimensions of HMSA

Table 1. Parameters design details of HMSA

Parameter	Ls	Ws	Hs	Lg	Wg
Value (mm)	39.96	38.52	1.59	9	39.96

Parameter	Lp	Wp	Lf	Wf
Value (mm)	17.3	20	11.32	3

3 Results and Discussion

The performance of a hexagonal shaped microstrip patch antenna for ultra-wideband has been investigated by using HFSS software. The proposed antenna structure provides return loss less than -10 dB for the frequency range of 3.1 - 10.6 GHz as shown in figure 4.

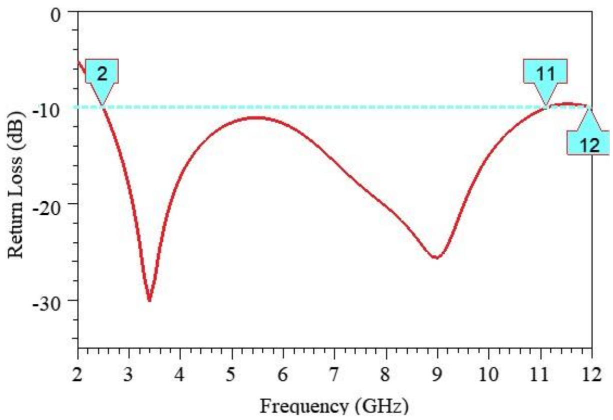

Fig. 4. Return loss verses Frequency of HMSA

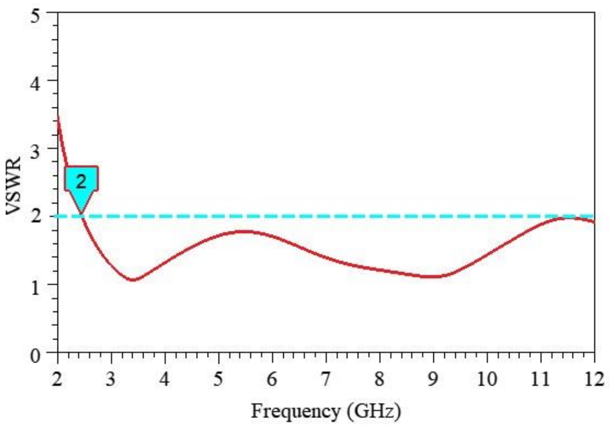

Fig. 5. VSWR verses Frequency of HMSA

Also, the VSWR of HMSA structure obtained is less than 2 for the frequency range of 3.1 - 10.6 GHz as shown in figure 5. The antenna structure provides the peak gain of 5.32 dB. The gain variations are shown in figure 6. The radiation efficiency obtained by the structure is 90.88 %. The H-plane and E-plane radiation patterns of HMSA at frequency 6.85 GHz are shown in figure 7.

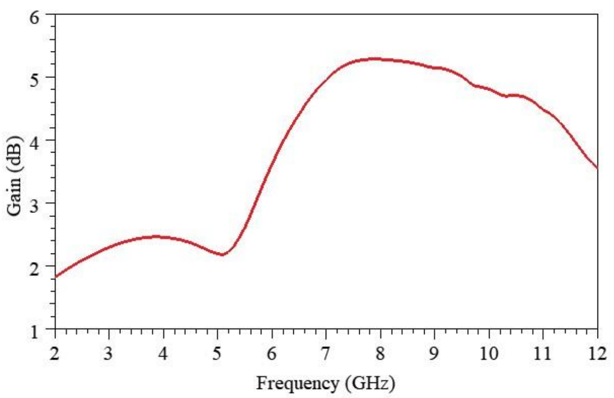

Fig. 6. Gain variation verses Frequency of HMSA

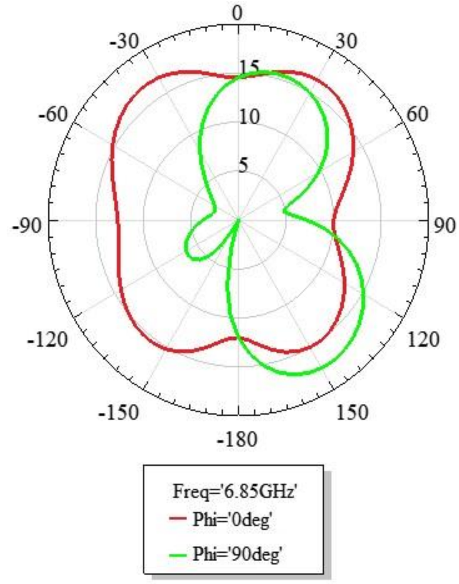

Fig. 7. E-plane and H-Plane Radiation Pattern of HMSA at 6.85 GHz

The simulated results of the proposed antenna structure are compared with the similar antennas present in the literature. The comparison is shown in table 2.

Table 2. Comparison with Literature

Ref. No.	Antenna Structure	Antenna Size (mm^2)	Gain (dB)
1	I-shaped dual C-slotted Rectangular MSA	0.5 x 6	2.45
2	Square ring shape antenna	35 × 20	5.2
4	Circular patch antenna with an open T-slot	30 × 35	4.1
8	Hexagonal MSA	30.4 × 35.4	3.6
Proposed Antenna	Hexagonal MSA	39.96 × 38.52	5.32

4 Conclusion

Here, the hexagonal shaped microstrip patch antenna is proposed. The antenna is made on a well-known FR4 substrate, which is frequently used to make printed circuit boards with a 1.59mm substrate thickness and a permittivity of about 4.4. The proposed antenna structure is simulated to operate in ultra-wideband frequency range covering a band from 3.1 to 10.6 GHz. The simulated result of hexagonal microstrip patch antenna provides the peak gain of 5.32 dB. The radiation efficiency of 90.88% is achieved. The designed antenna structure is useful for ultra-wideband applications.

Acknowledgment

The authors would like to thank our guide Dr. Ashwini Naik and co-guide Mrs. Sujata Kadam for their guidance and assistance to publish this paper. The authors are grateful to Dr. Mukesh D. Patil, Principal and also Dr. Chandrakant Gaikwad, Head of Electronics and Telecommunications Department at Ramrao Adik Institute of Technology for their support.

References

1. T. V. Padmavathy, P. Venkatesh, D. Bhargava1 and N. Sivakumar, Design of I-shaped dual C-slotted rectangular microstrip patch antenna (I-DCSRMPA) for breast cancer tumor detection, Springer (2018)
2. I. Amdaouch, O. Aghzout, A. Naghar, A. V. Alejos and F. Falcone, Breast tumor detection system based on a compact UWB antenna design, *Electromagnetics*, **64**, 123-133 (2018)
3. E. A. Aydin and M. K. Keles, UWB rectangular microstrip patch antenna design in matching liquid and evaluating the classification accuracy in data mining using random forest algorithm for breast cancer detection with microwave, JEET (2019)
4. X. F. Zhu and D. L. Su, A study of a compact microstrip-fed uwb antenna with an open T-slot, *Electromagnetics*, **13**, 181-189 (2010)
5. M. M. M. Ali1, A. A. R. Saad and E. E. M. Khaled, A design of miniaturized ultra-wideband printed slot antenna with 3.5/5.5GHz dual band-notched characteristics analysis and implementation, *Electromagnetics*, **52**, 37-56 (2013)
6. A. A. Shaalan & M. I. Ramadan, Design of a compact hexagonal monopole antenna for Ultra—Wideband applications, Springer (2010)
7. N. Kushwaha and R. Kumar, Design of slotted ground hexagonal microstrip patch antenna and gain improvement with FSS screen, *Electromagnetics*, **51**, 177-199 (2013)
8. A. S. Ali and D. Mathur, A novel UWB modified hexagonal microstrip antenna with improved gain, IJCE, **3** (2015)
9. X. Gong, L. Tong, Y. Tian and B. Gao, Design of a microstrip-fed hexagonal shape UWB antenna with triple notched bands, *Electromagnetics*, **62**, 77-87 (2016)
10. A. Kahwaji, H. Arshad, S. Sahran, A. Garba and R. I. Hussain, Hexagonal microstrip antenna simulation for breast cancer detection, IEEE (2016)
11. M. L. Naidu, Dr. B. R. Rao and Dr. C. Dharamraj, Implementation of octagonal and hexagonal microstrip patch antennas for UWB applications, SSRG IJECE, **3** (2016)
12. P. P. Singh and S. K. Sharma, Design and fabrication of a triple band microstrip antenna for WLAN, satellite tv and radar applications, *Electromagnetics*, **117**, 277-289 (2021)
13. J. M. Rathod, Comparative study of microstrip patch antenna for wireless communication application, IJIMT, **1** (2010)
14. S. T and C Nandagopal, Analysis on microstrip patch antennas for wireless communication, IEEE (2015)